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EXPERIMENTAL PROCEDURE FOR THE DETERMINATION OF COUNTING EFFICIENCY AND SAMPLING FLOW RATE OF A GRAB-SAMPLING WORKING LEVEL METER

M. GRENIER AND J. BIGU

ELLIOT LAKE LABORATORY

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by

M. Grenier* and J. Bigu**

ABSTRACT

The calibration procedures used for a working level meter (WLM) of the grab-sampling type are presented in detail. The WLM tested is a Pylon WL-1000C working level meter and it was calibrated for radon/thoron daughter counting efficiency (E), for sampling pump flow rate (Q) and other variables of interest. For the instrument calibrated at the Elliot Lake Laboratory, E was 0.22 ± 0.01 while Q was $4.50 \pm .01$ L/min.

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* Physical Scientist, ** Research Scientist and Radiation Project Leader, Elliot Lake Laboratory, CANMET, Energy, Mines and Resources Canada, Elliot Lake, Ontario, Canada.

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INTRODUCTION

Monitoring of the level of α-radiation activity is conducted routinely in underground uranium mines. This is done to ensure that workers are not exposed to conditions potentially hazardous to their health.

In the majority of uranium mines and derived industries, monitoring of α-activity is usually performed manually. In the last few years, however, several companies have designed and marketed radiation monitors which require a minimum of manual operation. These monitors combine a sampling head housing a filter and an α-detector facing the filter. The activity deposited on the filter during the sampling period gives a measure of the air radiation level. The sampling, waiting and counting periods, as well as the processing of raw data, are microprocessor-controlled. Sampling head, detector and electronics are protected by a compact, rugged dust-proof case.

The Pylon WL-1000C is a working level meter recently put on the market by Pylon Electronic Development Company*of Ottawa. The instrument is of the grab-sampling type, that is, it yields values of α-activity in terms of radon or thoron daughter concentration and working level (WL) each time a run is initiated.

Reliable data for the working level and the concentration of decay products can only be obtained if the instrument is properly calibrated. This implies determining the sampling pump's flow rate (Q) and the detector's counting efficiency (E). The WL-1000C has α-spectroscopic capabilities, hence alignment of voltage discriminators must be performed as well.

The Pylon instrument is presently under evaluation at the Elliot Lake Laboratory. The overall performance of the instrument as well as results of comparisons with conventional methods will be presented in a forthcoming report.

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* Commercial Firm, Ottawa.

The aim of this work is to lay out simple calibration procedures that should be followed periodically to ensure reliable operation of the instrument. These procedures may be generalized to apply to other environmental monitors. Values of E and Q as well as results of other tests obtained from calibration tests performed at the Elliot Lake Laboratory are given.

DESCRIPTION OF APPARATUS

PYLON WL-1000C WORKING LEVEL METER

The WL-1000C is 34.5 cm in height, 30 cm in width, 19 cm in depth, and its weight is approximately 6.8 kg. It is divided into two main sections. The lower portion of the instrument is a battery-pack section. It consists of rechargeable Nickel-Cadmium batteries. The upper portion houses a ruggedized α-detector of the Si-barrier type, as well as the microprocessor and the associated electronics. Sampling of air is implemented by means of a pump/filter holder unit connected to the upper section of the instrument by means of a cable (approximately 1 m long). Special filters mounted on plastic cards, eliminate the need for tweezers.

Several methods for measuring the radiation variables of interest are programmed into the microprocessor. These are two α-spectrometric methods (1), two Kusnetz methods (1,2), a Rollé (3) and a Tsivoglou (4) method. Also available is a short calibration routine, used to determine the instrument's detector counting efficiency and to verify the alignment of discriminator voltages.

The various routines (i.e., methods) programmed into the microprocessor, require values for the detector's counting efficiency (E) and the sampling flow rate (Q). These two variables may be entered manually just before sampling, otherwise default values programmed in factory will be used.

Another feature of the WL-1000C is its capability of analysis by

α-spectroscopy. Alpha-spectroscopy allows the instrument to discriminate radionuclides of different energy. To implement this feature, three discriminator voltages are adjusted, that set up three energy "windows". The discriminator voltages V_1 and V_2 ($V_1 < V_2$), define an energy region from E_1 to E_2 ($E_1 < E_2$). Alpha-particles of energy between E_1 and E_2 will be counted through "window" 1 (W1), while α-particles of energy between E_2 and E_3 ($E_2 < E_3$) will be counted in window W2 defined by V_2 and V_3 ($V_2 < V_3$). A third window, i.e., W3, counts α-particles of energy greater than E_3.

The discriminator voltages of the WL-1000C are set so that W1 counts α-particles from the decay of RaA (6.0 MeV) and ThC (6.1 MeV). Whereas windows W2 and W3 count α-particles from the decay of RaC^1 (7.7 MeV) and ThC^1 (8.8 MeV), respectively. However, because the energy difference between RaC^1 and ThC^1 is not large, there may be some overlap between windows W2 and W3. This overlap can be minimized by careful alignment of the discriminator windows by means of three adjustment potentiometers located in a covered recess on the face of the instrument.

RADIOACTIVE SOURCES AND OTHER CALIBRATING APPARATUS

The calibrating radioactive sources consisted of three Pylon Type-190 sources. These are: one Ra-226 source, one Th-228 source and one source that is a combination of both. A multi-channel analyzer (MCA) and an α-counter were also used. A wet-test gas flowmeter (WTGM) was used to calibrate the WL-1000C's sampling pump.

The Type-190 sources are calibrated by Pylon and are used to calibrate the WL-1000C's detector efficiency. They are also used to verify the discriminator alignment. All three sources have the same design, the only difference resides in the active material used in the source. The active material is glued inside a metal cup designed to fit over a tray that holds a Millipore*

* Commercial firm.

.8 µm filter. The cup/tray assembly is sealed with a rubber O-ring. As radon (thoron) gas grows inside the cup, the radon (thoron) daughters produced by the decay of the gas are deposited on the Millipore filter. These radioactive filters were used to calibrate the WL-1000C.

A Canberra (commercial firm, U.S.A.) series 30 MCA was used in conjunction with the WL-1000C every time a calibration test was made. The MCA is essential in the verification of discriminator voltages; it also provides a good visual check while the WL-1000C is counting. Hard copies of MCA results were kept using a Teletype printer. An X-Y plotter and a magnetic cassette recorder were also available as options.

A Tri-Met Instrument Ltd. Sample Counter (TM-372A) was used to cross check the calibration values given by Pylon for the Type-190 sources. The TM-372A scaler's efficiency was determined using calibrated Am-241 standard sources provided by the Ontario Ministry of Labour.

The flow rate (Q) calibration apparatus consisted of an American Meter Co. model 803 wet-test gas flowmeter (WTGM), as well as a U-tube mercury manometer connected as shown in Fig. 1. The WTGM uses the ratio of water to air volume displaced as a working principle. The number of revolutions of a needle on the face of the instrument is directly proportional to the volume of air moved. Thus the flow rate can be determined by timing one revolution of the needle.

EXPERIMENTAL PROCEDURES

The description of experimental procedures is separated into three sections. The first section describes the procedures followed to calibrate the WL-1000C's detector counting efficiency for radon and thoron daughters, i.e., E_{Rn} and E_{Th}, respectively. The second section describes the procedures

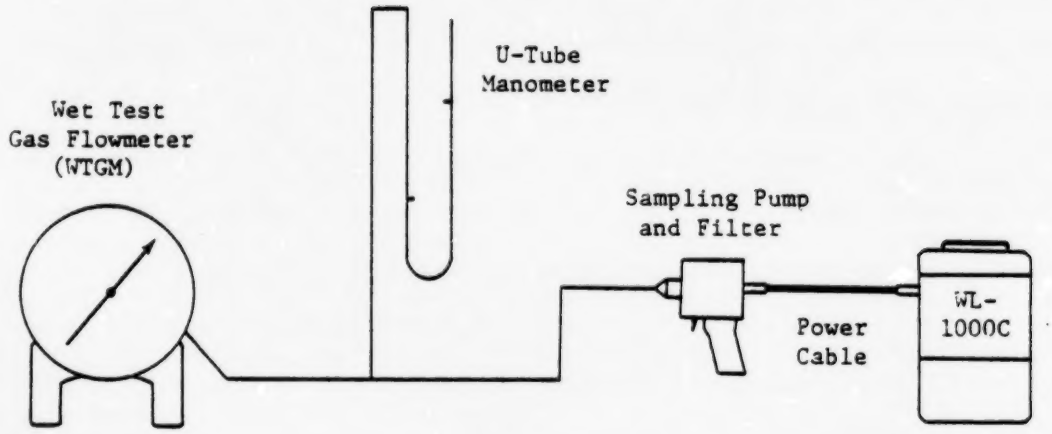

Fig. 1 - Flow rate calibration apparatus

used to verify the discriminator voltages alignment. The third section outlines the flow rate calibration procedures.

DETERMINATION OF THE RADON AND THORON DAUGHTER'S COUNTING EFFICIENCY

The WL-1000C counting efficiency was determined by means of the Pylon Rn-190 and Th-190 sources as well as the α-counter TM-372A. The latter was used to determine the α-activity of the Pylon sources used to calibrate instruments such as the WL-1000C. Although the Pylon sources were precisely designed to calibrate Working Level meters, this could not be done directly because their activity, as determined at the factory, was found to be in error.

The radioactive filter is produced by placing a Millipore filter in the radon (thoron) daughter type-190 source for a period of at least 24 hours. This period is referred to as the ingrowth time, t_{in}. As the filter is removed from the source, the calibrating routine programmed into the WL-1000C is started simultaneously. From then on, one minute is available to mount the filter on a Pylon filter card and to insert it into the detector slot. After the one minute delay, the instrument automatically proceeds to a 5 minute count in all three energy windows. Once the routine is completed, three 6-min counts, labelled $C_1(1\rightarrow6)$, $C_2(1\rightarrow6)$ and $C_3(1\rightarrow6)$, corresponding respectively to α-counts in W_1, W_2 and W_3, may be retrieved from the WL-1000C. These counts in conjunction with the source strength, are used to calibrate the instrument according to analytical procedures indicated below.

As soon as the calibrating routine is completed, two minutes are available to remove the filter from the filter card and place it in the TM-372A counter for a 15 minute gross α-count, labelled $C(8\rightarrow23)$ since it extends from the 8th to the 23rd minute after removal of the filter from the source. The $C(8\rightarrow23)$ count was used to determine the Pylon sources' strength.

PROCEDURE FOR VERIFYING AND ALIGNING DISCRIMINATOR WINDOWS

The 6 minute calibration routine described above is also used in conjunction with the MCA to align the discriminator windows of the instruments. In this instance, however, a mixed Ra-226/Th-228 source is used to produce an active filter for spectral purposes only. At the end of the calibrating run one has three counts from the WL-1000C and a spectrum that consists of three distinct peaks on the screen of the MCA. The total of the three WL-1000C counts should be equal to the integral counts under the peaks of the MCA.

Upon examination of the high energy end of the spectrum, one notices that past a certain channel number, no more counts can be found. A region of interest (ROI) is then defined from that channel down to a lower energy channel until the total α-count in that region is as close as possible to $C_3(1\rightarrow6)$, without being larger. Similarly, two other ROI are defined using the α-counts $C_2(1\rightarrow6)$ and $C_1(1\rightarrow6)$.

After the three ROI are set, visual examination of the MCA screen will indicate whether or not the discriminators are properly aligned. Since the counts in each energy window are supposed to represent distinct radionuclides, alignment is considered good if the three peaks fall clearly in their respective ROI. Figures 2 and 3 show examples in which ROI have been set as described above. From Fig. 2 one can conclude that the discriminators are well aligned.

Figure 3 shows misaligned discriminators. Discriminator windows are adjusted by using the potentiometers under a cover on the face of the instrument. In this case, the alignment procedure has to be repeated until results as those shown in Fig. 2 are obtained.

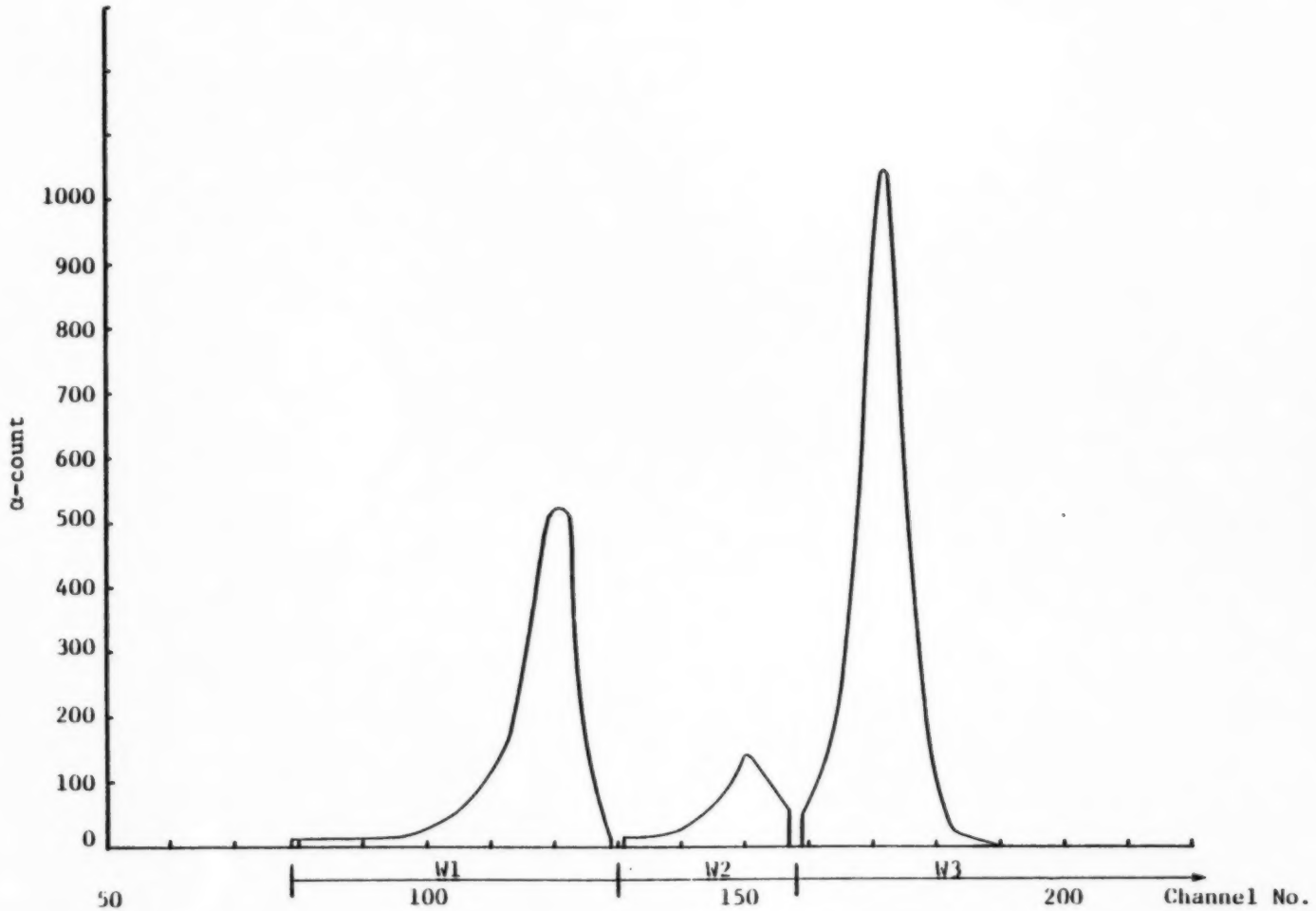

Fig. 2 - MCA spectrum showing properly aligned discriminators. Discriminator voltages define energy regions (W1, W2 and W3) that start and end at the places of minimum count amplitude.

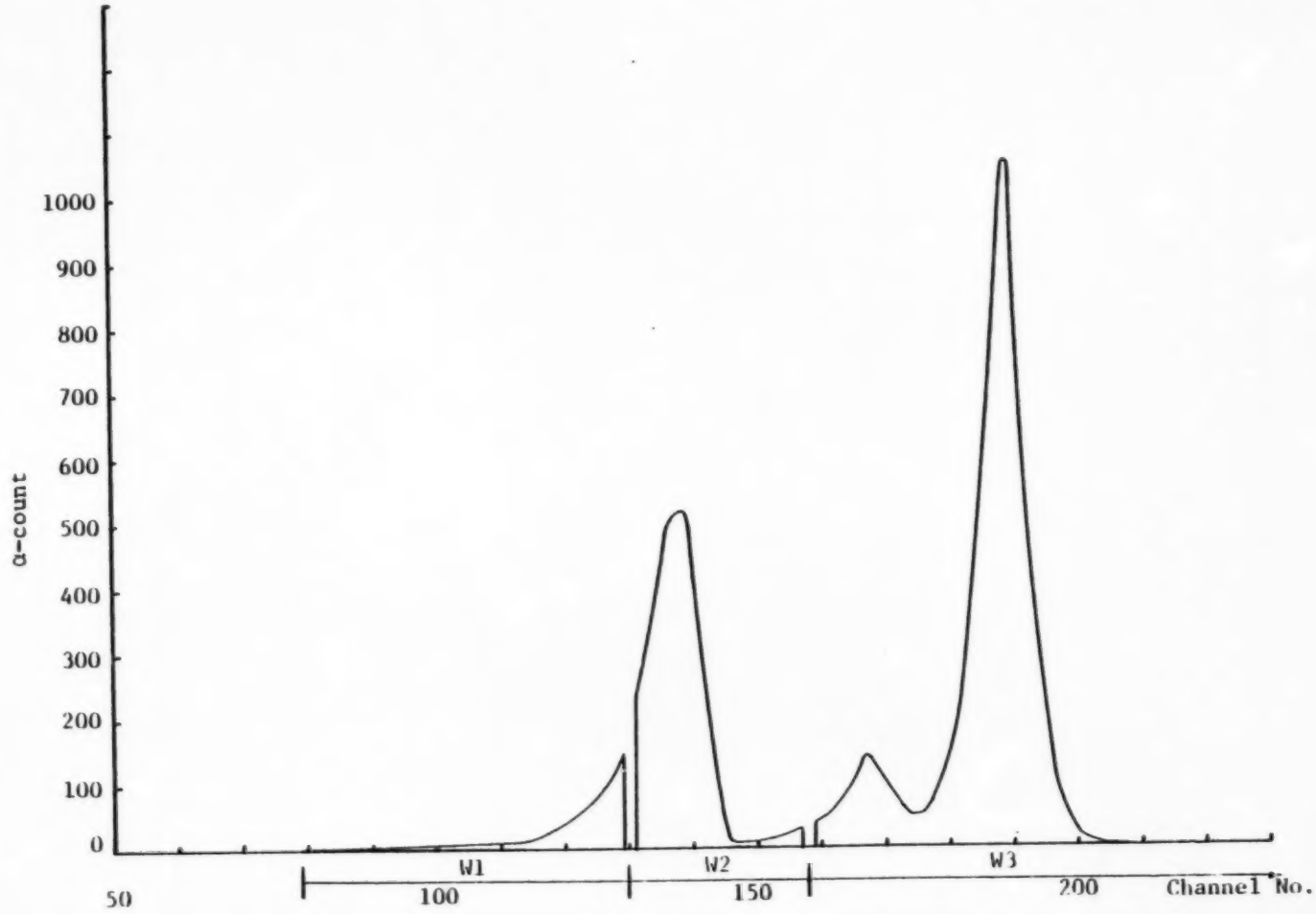

Fig. 3 - MCA spectrum indicating misadjusted discriminator voltages.

DETERMINATION OF THE SAMPLING FLOW RATE

To calibrate the sampling pump flow rate of the Pylon instrument, the apparatus shown in Fig. 1 was set up. The pump was plugged into the main unit of the WL-1000C and a special fitting was designed and glued on the sampling head to accommodate a length of tubing leading to the wet-test gas flowmeter (WTGM). To reproduce real sampling conditions, a filter card was placed in the sampling head.

Once the circuit is connected, a sampling routine (say the thoron α-spectroscopic routine) is selected and started. This will activate the pump for a period of 10 minutes. From the time for one full revolution of the WTGM needle, one can calculate the flow rate of the sampling pump.

EXPERIMENTAL RESULTS AND CALCULATIONS

RADON DAUGHTER COUNTING EFFICIENCY

The Pylon 190 sources were designed to determine the α-counting efficiency of instruments such as the WL-1000C. The efficiency is calculated by means of (5):

$$E = \frac{C(a \rightarrow b)}{S \times Y \times F(a \rightarrow b) \times (1 - e^{-\lambda \times t_{in}})} \qquad \text{Eq 1}$$

where, E is the instrument's counting efficiency

$C(a \rightarrow b)$ is the gross α-count in time period a to b

S is the Pylon 190 source strength

Y is the ratio of Millipore filter area to total inner Type-190 source area

$F(a \rightarrow b)$ is a correction factor for the a to b time interval (5)

λ is the decay constant of radon gas (radon daughter counting efficiency) or thorium B (thoron daughter counting efficiency)

t_{in} is the ingrowth time in the Type-190 source.

Using the calibration routine of the WL-1000C, Equation 1 becomes:

$$E_{Rn} = \frac{C_T(1 \rightarrow 6)}{S \times Y \times F(1 \rightarrow 6) \times (1 - e^{-.000126\ t_{in}})} \qquad \text{Eq 2}$$

where, $C_T(1 \rightarrow 6)$ is the sum of $C_1(1 \rightarrow 6)$, $C_2(1 \rightarrow 6)$ and $C_3(1 \rightarrow 6)$

$Y = .1023$ is the area ratio

$F(1 \rightarrow 6) = 7.381$ as per Pylon specifications

$\lambda_{Rn} = .000126\ min^{-1}$ is the radon gas decay constant.

Therefore, Equation 2 becomes:

$$E_{Rn} = \frac{C_T(1 \rightarrow 6)}{.755\ (1 - e^{-.000126\ t_{in}}) \times S} \qquad \text{Eq 3}$$

Equation 1 can also be used to determine the source strength of the Pylon sources by means of the TM-372A as indicated above, thus:

$$S = \frac{C(a \rightarrow b)}{E \times Y \times F(a \rightarrow b) \times (1 - e^{-\lambda Rn \times t_{in}})} \qquad \text{Eq 4}$$

where, $C(a \rightarrow b)$ is the TM-372A $C(8 \rightarrow 23)$ gross α-count

E is the TM-372A's counting efficiency ($E = .4421$ as per calibration with Am-241 standard sources)

$Y = .1023$

$F = 14.907$ is the Pylon correction factor for the $8 \rightarrow 23$ minute counting interval (5).

Hence, Equation 4 may be rewritten as:

$$S = \frac{C(8 \rightarrow 23)}{.674 \times (1 - e^{-.000126\ t_{in}})} \qquad \text{Eq 5}$$

The α-counting efficiency for radon daughters for the WL-1000C can be calculated by means of Equation 3 whereas the value of S can be obtained by Equation 5. Table 1 shows results obtained for three independent tests. The ingrowth time varied from 1320 to 3960 minutes. $C_T(1 \rightarrow 6)$ and $C(8 \rightarrow 23)$, as well as the source strength are shown in Table 1. The radon daughter counting efficiency is also shown for the three experiments. From these, an average value for E_{Rn}, is found to be 0.210 with a mean deviation of 0.005.

Table 1 - Experimental data for E_{Rn}

Test	t_{in}(min)	$C_T(1 \rightarrow 6)$	$C(8 \rightarrow 23)$	S(dpm)	E_{Rn}
1	3960	14938	62227	235020	.2143
2	1320	4761	16148*	193378	.2128
3	2820	4359	19191	95212	.2028

* the TM-372A counting period used in this case was $C(24 \rightarrow 39)$, see ref.(5).

Figure 4 shows a typical MCA spectrum obtained during a calibration test. The horizontal axis shows the channel numbers while the vertical axis shows the counts in each channel. The leftmost peak is that of RaA while the other one is that of RaC^1. The three WL-1000C counts are shown in the top left-hand corner, while the numbers under the peaks represent ROI's set to match the WL-1000C counts as closely as possible.

THORON DAUGHTER COUNTING EFFICIENCY

The procedure followed in this case is similar to that described in the previous section. The only differences are that the decay constant to be used is that of ThB ($\lambda_{ThB} = .00109\ min^{-1}$), and that because of different source geometry used, the area ratios were different. The Pylon F factors are different as well. Therefore, in the case of thoron, Equations 3 and 5 become:

$$S = \frac{C(8 \rightarrow 23)}{.813 \times (1 - e^{-.00109\ t_{in}})} \qquad \text{Eq 6}$$

$$E_{Th} = \frac{C_T(1 \rightarrow 6)}{.427 \times (1 - e^{-.00109\ t_{in}}) \times S} \qquad \text{Eq 7}$$

Table 2 shows experimental data pertaining to two different tests. Figure 5 shows the MCA spectrum associated with one of the tests.

DISCRIMINATOR ALIGNMENT

Discriminator alignment tests were done using the combination Rn/Th source. Three tests were conducted. Figures 6 and 7 show spectra for one such test. The contribution from the different radon and thoron daughters are indicated. Figure 6 shows a spectrum taken immediately after removal of the filter from the source. Figure 7 shows the same spectrum four hours later, i.e., after the radon daughters have decayed away. Also indicated in these spectra are the discriminator windows, the ROI and the integral α-count under each peak.

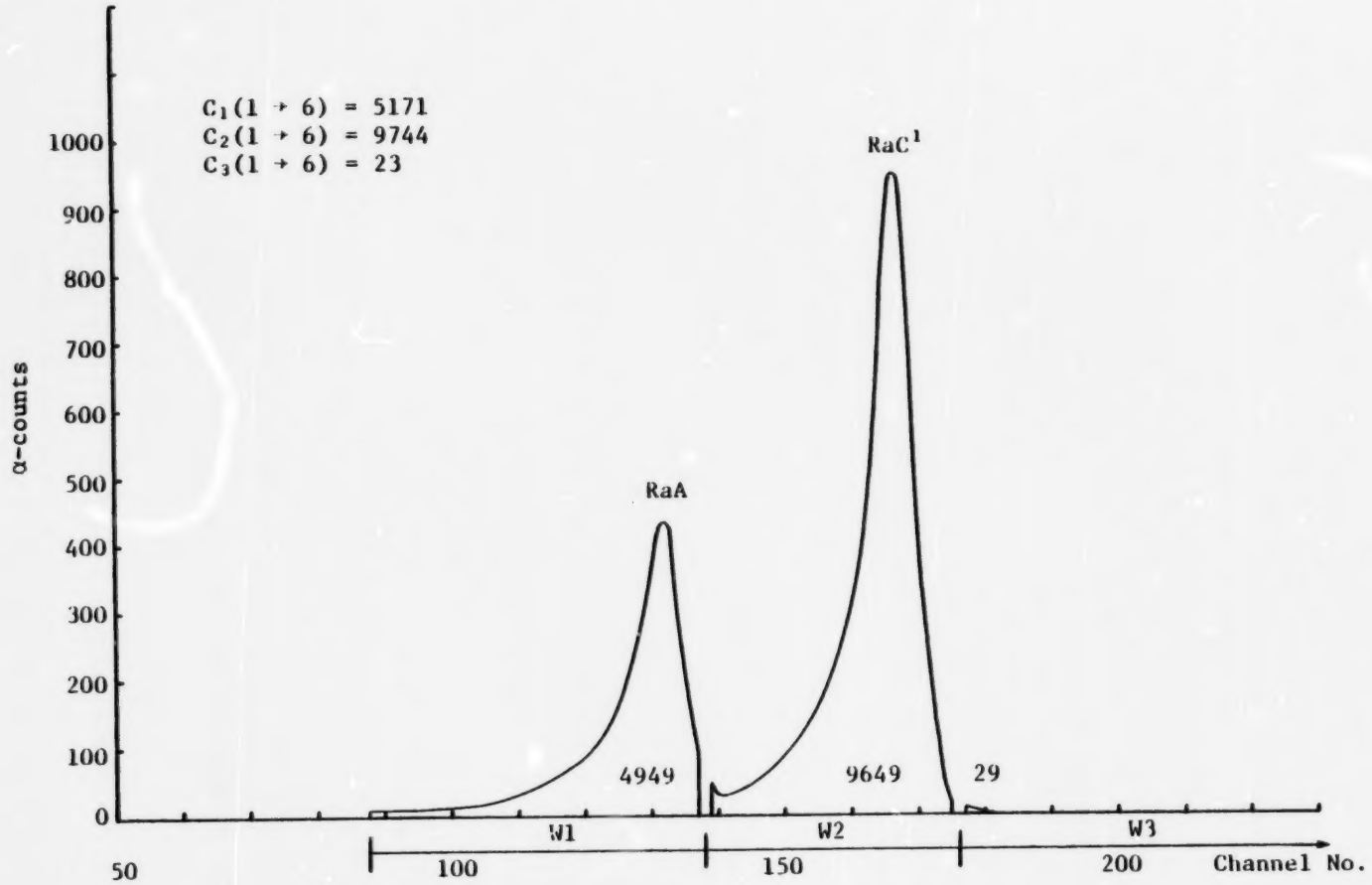

Fig. 4 - MCA spectrum for radon daughter efficiency calibration test #1. The counts in each ROI as well as $C_1(1 \rightarrow 6)$, $C_2(1 \rightarrow 6)$ and $C_3(1 \rightarrow 6)$ are shown as well (these parameters are also shown in Fig. 5, 6 and 7).

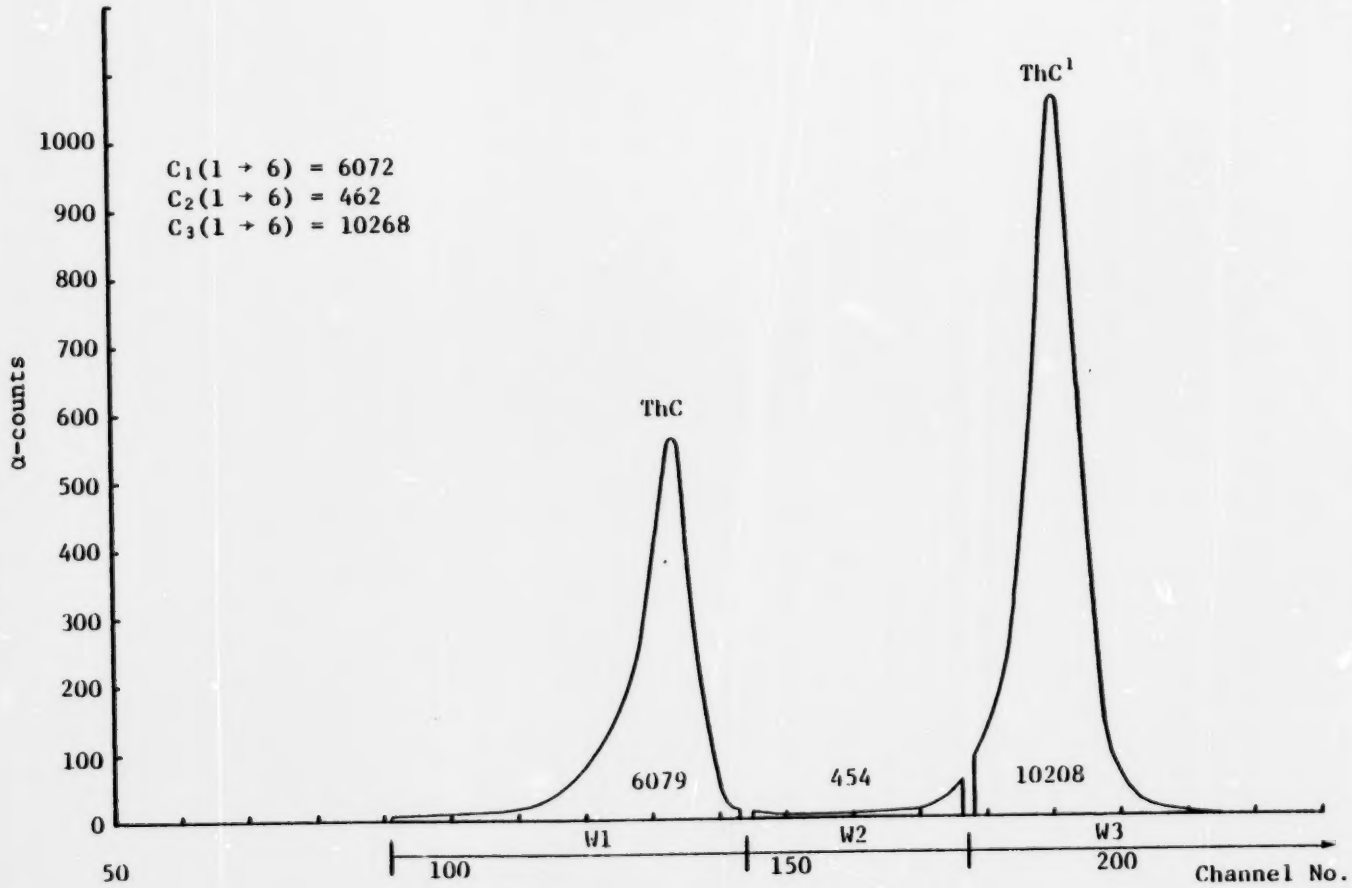

Fig. 5 - MCA spectrum for thoron daughter efficiency calibration test #1.

Table 2 - Experimental data for E_{Th}

Test	t_{in}(min)	$C_T(1 \rightarrow 6)$	$C(8 \rightarrow 23)$	S(dpm)	E_{Th}
1	1140	16802	139251	240776	.2297
2	5737	23897	197900	243889	.2299

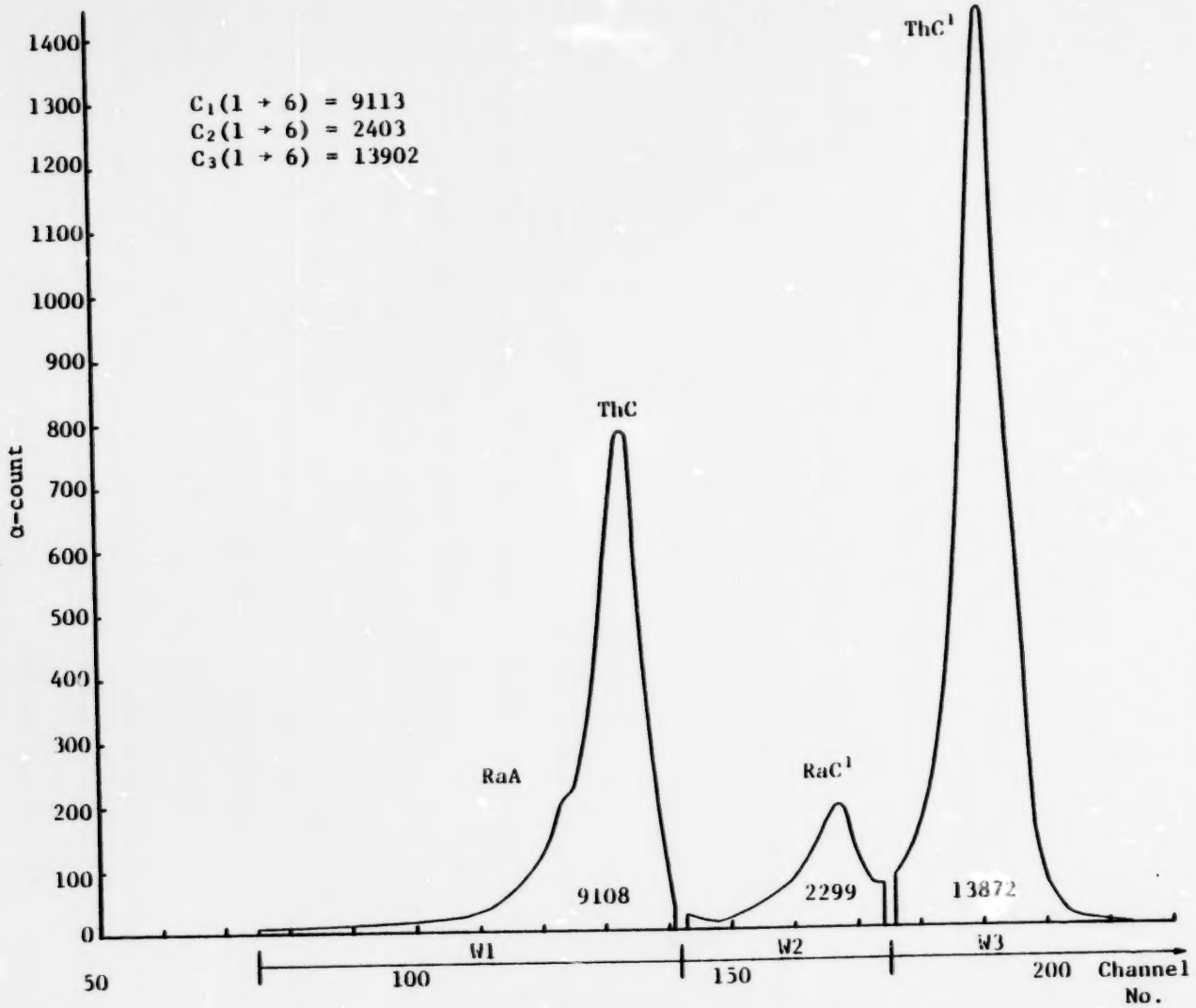

Fig. 6 - MCA spectrum for a discriminator alignment test done immediately after removal of the sample from the Pylon 190 Rn/Th source.

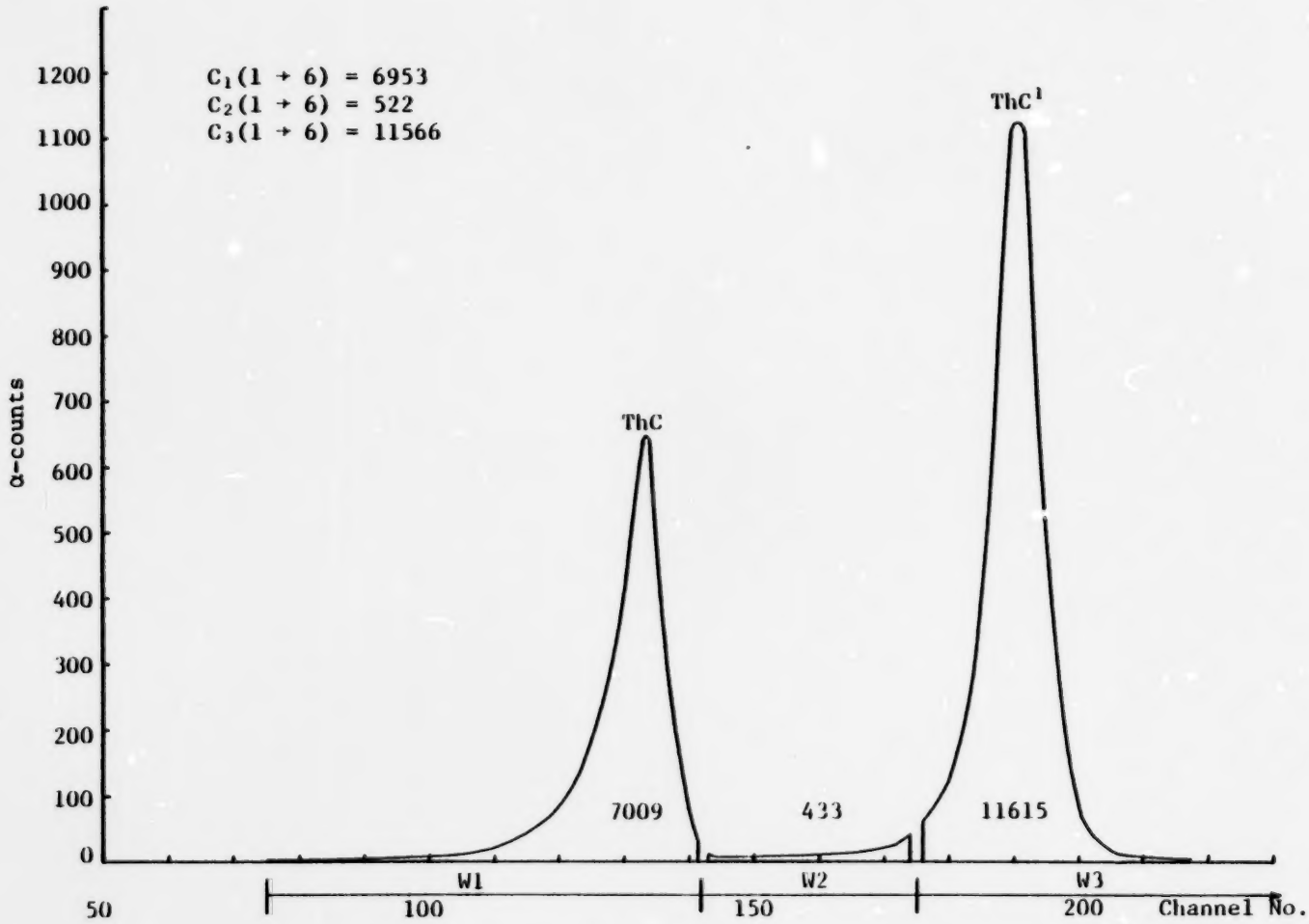

Fig. 7 - MCA spectrum for the discriminator alignment tests using the same filter as that of Fig. 6 (4 hours later to allow radon daughters to decay).

FLOW RATE CALIBRATION

The wet test gas meter's (WTGM) needle does one full revolution when 2.83 liters of air is pumped through it. The time for one revolution was measured in seconds. The flow rate for the WL-1000C pump can be obtained by:

$$Q = \frac{2.83}{t_R} \quad (L/s) \qquad \text{Eq 8}$$

where, t_R is the time for one revolution of the WTGM's needle. Table 3 shows results for three flow rate calibration experiments.

DISCUSSION OF RESULTS AND CONCLUSIONS

The average value for radon and thoron counting efficiency was found to be 0.210 and 0.223, respectively. These values have been measured several times with excellent reproducibility.

Table 1 shows that the Ra-226 Type-190 source strength varies substantially, as determined by TM-372A measurements. For this reason, when the calibration tests were conducted according to Pylon's instructions and source strength, the values of E were found to fluctuate significantly, e.g., in the 0.1 to 0.26 range. It is apparent that a problem intrinsic to the Type-190 sources exist. These problems will be examined in a forthcoming MRL report.

The α-counting efficiency is known to be a function of α-particle energy. Because the TM-372A counter was calibrated with Am-241 sources (E = 5.48 MeV), the TM-372A's E value of 0.442 might not be truly representative of the counting efficiency of the instrument at high α-particle energies such as those corresponding to radon (and thoron) daughters. Using the TM-372A's α-counting efficiency for Am-241 sources, a combined thoron/radon daughter counting efficiency of 0.22 ± 0.01 was found, where 0.01 is the mean deviation of

Table 3 - WL-1000C sampling pump flow rate calibration

Test	Time for one revolution(s)	Q(L/s)	Q(L/m)
1	37.7	.0751	4.5060
2	37.9	.0747	4.4820
3	37.6	.0753	4.5180

$\overline{Q}$ = 4.502 ± .013 L/m

measurements from the average efficiency. The procedure used to arrive at this figure is relatively simple. The possibility for considerable improvement exists, if accurately determined values of the Type-190 source strength were available.

The verification and alignment of discriminators is a rather qualitative procedure. Results from the previous section show good discriminator adjustment. This can be seen in Fig. 6 and 7 where the discriminator positions are exactly in the minimum amplitude region between peaks. Normal handling of the instrument did not shift the discriminators since several discriminator alignment tests were done with excellent reproducibility. Discriminator misalignment may be corrected by adjusting the potentiometer screws described above.

The average flow rate measurement was found to be 4.5 L/m when a "blank" filter was placed in the sampling head in order to reproduce real sampling conditions. The experimentally determined values of E and Q were programmed into the WL-1000C when it was taken in the field.

ACKNOWLEDGEMENT

The authors would like to thank Pylon Electronic Development Co. for the loan of the WL-1000C Working Level Meter with which the tests were conducted.

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